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# **Experimental Assessment of Problem Solving at the Combined Arms and Services Staff School**

**James W. Lussier, Robert E. Solick,  
and S. Delane Keene**

U.S. Army Research Institute

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FOREWORD

The U.S. Army Research Institute for the Behavioral and Social Sciences Fort Leavenworth Field Unit conducts a systems and training research program in support of the Combined Arms Center.

The Field Unit at Fort Leavenworth has been involved for several years in research to assess and improve decision making in command groups. Studies have been conducted in the field, the classroom, and the laboratory.

The research described in this paper is a major step forward because it identifies a type of group problem characterized by a high degree of distribution of task responsibility. Distribution of responsibility is typical of the decision making of command groups, yet virtually none of the psychological research in group decision making addresses this problem-solving situation. This paper also describes the first experimental use of the VARWARS problem, which provides an effective tool for objectively and reliably measuring group performance.

This effort was performed with the support of the Combined Arms and Services Staff School.

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## EXPERIMENTAL ASSESSMENT OF PROBLEM SOLVING AT THE COMBINED ARMS AND SERVICES STAFF SCHOOL

### EXECUTIVE SUMMARY

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#### **Requirement:**

In the decision-making procedure of military command groups, an overall problem is divided into subproblems, and individuals or subgroups work to produce solutions in their functional areas of expertise. Eventually the solutions of the subgroups are combined to produce an overall plan of action or solution to the problem. This method of problem solving can be difficult because the solvers are working in parallel on separate but interdependent problems. If the subsolutions are to combine in an integrated and complementary fashion, the solvers must share information and coordinate their solutions as they develop them. The research literature in the area of group decision making and problem solving focuses on groups that, like a jury, do not divide responsibility for various tasks among their members. Many of the findings based on the jury-type groups do not seem to be applicable to the area of command group problem solving.

The major goal of the Combined Arms and Services Staff School (CAS<sup>3</sup>) is to improve students' problem-solving and communication skills. CAS<sup>3</sup> asked the U.S. Army Research Institute for the Behavioral and Social Sciences to develop a test that objectively measures group problem-solving abilities and to use the test to compare the performance of captains entering CAS<sup>3</sup> with the performance of captains graduating from CAS<sup>3</sup>. This project required the development of a test instrument that distributed task responsibility. Such an instrument would satisfy both the specific need of CAS<sup>3</sup> and the general need for group problem-solving research that is relevant to U.S. Army command groups.

#### **Procedure:**

A problem called "VARWARS" was developed to meet the requirement. VARWARS is a group planning and resource allocation exercise set in the context of acquiring, staffing, and planning for use of a hypothetical training device. A 7-person problem-solving group divides into teams that work on interdependent subproblems. Each VARWARS solution is objectively scorable. In addition, the problem-solving process is evaluated using a set of scales developed to measure decision making, organizational ability, information sharing, professionalism, and leadership.

In the first experiment, groups of students entering CAS<sup>3</sup> and groups graduating from CAS<sup>3</sup> participated in VARWARS exercises. In the second experiment, groups midway through instruction participated. In the third

experiment, groups composed of students from the same class section were compared with groups composed of students who had not worked together while at CAS<sup>3</sup>.

**Findings:**

Students showed a progressive and significant decline in VARWARS scores. Intact groups (from the same class section) performed significantly worse than groups composed of students from different sections. The process variables studied did not show a strong relationship to the VARWARS product scores. Both graduate and entrant groups used similar decision-making processes, but the graduate groups were much more prone to mistakes in implementation. The VARWARS score appears to be a sensitive, reliable measure of group performance.

**Utilization of Findings:**

The counterintuitive results of this study have raised questions that remain to be resolved. Basic principles concerning effective problem solving in groups with distributed responsibility have yet to be developed. The VARWARS exercise is a good tool for continuing the investigation. CAS<sup>3</sup> has made a major effort to expand and strengthen its problem-solving instruction and has included the VARWARS exercise as a regular part of its curriculum.

**EXPERIMENTAL ASSESSMENT OF PROBLEM SOLVING AT THE COMBINED ARMS AND SERVICES STAFF SCHOOL**

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# EXPERIMENTAL ASSESSMENT OF PROBLEM SOLVING AT THE COMBINED ARMS AND SERVICES STAFF SCHOOL

## Introduction

### Overview

In a typical group problem solving experiment, the members consider the problem, generate ideas, and may propose several alternative solutions. Eventually a group solution is reached. Delphi groups and juries are examples. Researchers studying this type of problem solving may be interested in how the group solutions differ in character or quality from solutions produced by an individual, in the decision making process of solution development and selection, or in the factors that influence a given member's persuasiveness.

This paper describes research involving a form of group problem solving that differs significantly from the more commonly studied situation described above. In this second general class of group problem solving, the members do not all work on the same problem; rather, the problem is divided into subproblems and the group members work to produce subsolutions that must be integrated into a whole solution. In the most difficult of these cases, the subproblems are highly interdependent. An individual subsolution cannot be evaluated as good or bad in isolation; it is only effective insofar as it complements and supports the other subsolutions. Thus the group members must work on their problems in parallel but require knowledge of the other members' solutions. This situation may be further complicated when some resources are owned by the group as a whole. Each subgroup cannot be exactly sure what resources it will have to solve its subproblem because this will depend on the resources consumed by the other subsolutions.

A problem called VARWARS, which requires a high degree of distribution of task responsibility, was developed for this research. VARWARS is complex enough to allow many plausible approaches to solutions and yet is sufficiently well defined to enable objective and quantitative scoring of the quality of the solutions. The VARWARS problem was administered to groups of students entering and graduating from the nine-week course of the Combined Arms and Services Staff School (CAS<sup>3</sup>). Major goals of the course are to improve the problem solving and communication skills of its students. The goals of this research were to experimentally assess student progress in problem solving and to develop a method for evaluating group problem solving skills.

In addition to the overall measure of solution quality, group process was evaluated using a set of scales developed to measure organizational ability, information sharing, decision making, professionalism, and leadership. A team of observers rated groups on the process variables in order to identify areas of weakness in the students and to investigate the relationship between process and product.

The experiment was designed to answer three main questions:

- (1) Are graduates of CAS<sup>3</sup> more effective problem solvers than entrants?
- (2) Do graduates use the problem solving techniques they are being taught?
- (3) Are the techniques themselves effective?

### Group Problem Solving

There are important differences between the two types of group problem solving situation described above. In many cases, factors may have opposite influence. In the jury-type situation groups tend to be slower than individuals. In simple reasoning (Klugman, 1944), complex problem solving (Fox and Lorge, 1962), and brainstorming (Taylor, Berry, and Block, 1958) groups were less productive than individuals. Although not all studies have demonstrated this effect, it is reasonable that increasing group size will in general slow problem solving. Time spent explaining solutions, discussing methods, polling opinions, or dispersing information may increase solution quality but reduce output. This might be particularly true in tasks where one or two key individuals are doing the actual solving or decision making and the rest of the group are assisting or observing. The group may also be slowed significantly when consensus or general group approval is required. Groups working in the VARWARS-type situation, where the problem is subdivided, can, in contrast, often perform much faster than individuals. Group members or subgroups can work different aspects of the problem independently and simultaneously. Both types of groups will tend to be outperformed by individuals if the comparison is done in person-hours because in both groups an amount of effort must be given to coordinating and communicating which can be viewed as overhead to actual task performance. Parallel processing in computing is a good analog to the VARWARS-type situation. Computer tasks can be performed much faster by N processors working cooperatively than by a single processor, but the amount of coordinating tasks increases with N and the time savings typically fall far short of reducing the task time to 1/Nth.

When quality of the output is considered, the two types of situations also present a strong contrast. Jury-type situations typically produce more accurate, higher quality solutions than individuals (e.g. Anderson 1961; Taylor and Faust, 1952; Davis and Restle, 1963). One skilled or intelligent member, who is also persuasive, can greatly increase the quality of the group result, especially in tasks where breakthrough reasoning, insight, or flawless analysis are important. Where specific knowledge is important to the task, the jury-type group may be working from a knowledge base that is essentially the union of the knowledge bases of the individual members. Therefore, performance at or above the quality level of the most proficient member is not at all uncommon. Statistically, the quality of this most proficient member will increase as group size increases. Depending on the nature of the task, problem solving in the VARWARS-type group may show just the opposite effect. For example, in the development of a new product the manufacturing and distribution divisions may perform brilliantly when compared to routine performance. As a result they can produce 10% more output and locate the product in stores around the country at 10% less cost than expected. If, however, marketing has failed miserably and

the product gets a very negative image, the outcome of the entire project may be poor. Like a machine, functioning at the level of its weakest part, the solution quality of VARWARS-type groups often is limited by the least proficient member or subgroup. In some instances, none of the subgroups may be doing their tasks poorly but the group output suffers through lack of integration. Statistically, the more members or subgroups the VARWARS-type situations have, the weaker will be the least proficient member. In a rough sense, the quality of the efforts of the individual members in the jury-type problem combines in an additive or conjunctive fashion with weak members adding little or nothing to the group output and strong members having the greatest influence. In the VARWARS-type problem, the member efforts tend to combine in a more complex, multiplicative, or disjunctive fashion with the weakest members having the greatest influence, often negating the significance of the quality of the strong member contributions.

The bulk of the experimental literature in group problem solving involves studies of jury-type group situations. Kelley and Thibaut, (1969), in the Handbook of Social Psychology, sum up their description of the performance of groups as "slow but sure". Group problem solving in VARWARS-type situations could, however, be termed as fast and faulty. We believe most group problem solving situations, outside the laboratory, fall more into the VARWARS-type rather than the jury-type situation. Complex problems in particular very often require so much expertise that it is unreasonable to expect one person (or one or more members of the group) to have (or to acquire) the ability to solve the problem. It is equally unreasonable to expect each member of the group to work through each aspect of the problem together. Many group problem solving situations may, on the surface, appear to be jury-type, for example the activity of various committees. Often however, committee members will each have various areas of expertise and responsibility. Each may be expected to analyze the problem from a particular perspective and present estimates and analyses for the other members to weigh in making the decision. There are strong elements of the VARWARS-type situation here, where the analyses from different perspectives actually represent subproblems and only the presenter is in a good position to judge the quality and accuracy of his contribution.

#### The Combined Arms and Services Staff School

CAS<sup>3</sup> is a 9-week course now given to all U.S. Army officers when they are approximately one-third of the way through their careers. Most students are captains in rank although some are majors. The course is designed to teach the fundamental skills required of staff officers at the brigade level and above. The goals of the course are to improve the students written and oral communication and problem solving abilities. The students are assigned to 12 person groups that live and work together and are trained by a single instructor. CAS<sup>3</sup> instructors, or staff leaders, are lieutenant colonels and, for the most part, are a select group of officers of this rank who have been especially successful in their careers.

Students are taught to follow a six-step analytic problem solving method composed of the following steps: identify the problem, gather information, generate alternative solutions, analyze the alternatives, decide, and implement

the solution. During the course, the students are given several decisionmaking exercises. They work as a group to reach a decision, prepare a briefing to explain and justify their decision and present the briefing to their instructor who critiques their performance. Kaplan and Kiyohara, (1985) examined instructor ratings of entering and graduating students and found evidence of improved briefing style: better gestures, movement, eye contact, volume and rate of delivery. The content of the briefings, however, were not rated as better.

#### The VARWARS Problem

VARWARS is a group planning and resource allocation exercise which is set in the context of acquiring, staffing and employing a new, hypothetical, training device. The VARWARS problem was developed such that:

1. The quality of the group solution is numerically scorable in an objective manner.
2. The subproblems exhibit considerable dependency, including sharing of a common pool of resources.
3. There is not a single correct answer, for example, as in a math problem. There are many good answers.
4. The presentation by the group of their solution is very simplified so that group score depends on the quality of the problem solving rather than the presentation of the solution.
5. All solutions are scorable, even "defective" solutions.
6. Problem elements are straightforward so that group success depends more on the ability of the group to share information, make decisions, integrate the subsolutions and otherwise function effectively than it does upon the creativity or insight of a single member.

In the VARWARS exercise, a leader is assigned, and the remaining members of the group divide themselves into three two-person teams: a Budget Team, a Training Team, and a Personnel Team. In addition to general instructions received by all members, each team and the leader receives packets of individual instructions and information. In order to effectively solve the problem, each team requires information originally provided to the other teams and the leader. The teams also depend on one another for intermediate products such as estimates and assessments.

Although it is not made explicit in the VARWARS instructions, the VARWARS problem may be viewed as a two-phase resource allocation problem. The group begins with a fixed amount of resources: 15 million dollars and 150 weeks. In the first phase, the Budget and Personnel Teams convert the initial resources into a potential for providing VARWARS training. A number of VARWARS machines are purchased, operators are hired to run them, and money is set aside for maintenance and operating costs. As a result of Budget and Personnel decisions, the Training Team is provided with a fixed amount of resources: a number of devices, each with an established capacity for training, and some money

budgeted to pay for travel of the trainees. In the second phase of the problem, the Training Team must convert these resources to points by locating the devices at military installations and scheduling units for training on the device. Work on both phases, however, proceeds concurrently.

Although the number of the variables involved makes the VARWARS problem complex, the scoring concept is relatively simple. The group converts a fixed amount of resources into points. The more efficiently they perform this operation the more points they will score. The VARWARS score is based on the point system described in the Leader's Instructions. There are 88 military units eligible for training in the problem, composing five different types of unit: active corps, active divisions, active brigades, reserve divisions, and reserve brigades; points are awarded for each unit in accordance with the number of persons trained from that unit and in accordance with the type of unit. The analysis and scoring of VARWARS solutions is done by a computer program.

The group score depends, of course, on the quality of the decisions made, e.g., which model devices are purchased or where the devices are located. Also, the group score depends greatly on the amount of resources that are wasted by misunderstandings and poor decisions, e.g., the Training Team uses only a small fraction of the resources that have been developed by the other teams, or the Personnel Team consumes such a large portion of the total budget that the other teams have only enough resources to use a small fraction of the personnel hired.

The score the group receives is clearly not a reflection of the sum of the quality of the individual team products. The team products are highly interdependent. If one team produces a product which is not well integrated with the other team products, then the group score may be drastically reduced. Therefore, the group score is more similar to a multiplicative function of the individual team products than it is to an additive function.

A detailed description of the VARWARS Problem may be found in Varwars: A Group Problem Solving Exercise (Lussier, 1988).

#### Experiment 1 Methods

##### Participants

Twenty-two problem solving groups, consisting of seven members each, participated in the experiment. Group members were U.S. Army Captains attending one of three rotations at CAS<sup>3</sup>. Eleven of the groups, the entrant groups, were composed of captains randomly selected during registration for the course. The entrant groups were tested during one of the two weekdays immediately preceding the first day of instruction. The other 11 groups, the graduate groups, were composed of officers in the seventh week of the nine-week course. Members of each graduate group were drawn from different class sections, so members had not worked together while at the course. Graduate group members were selected to match entrant group members on branch of service, and on a diagnostic test of quantitative skills given routinely to all students.

### Procedures

Groups were tested at the ARI Fort Leavenworth small group laboratory which provides videotape recording and observation of the group through a one-way mirror. Each session commenced with a brief introduction by a researcher. During the introduction, the senior member of the group was assigned the position of group leader, equipment and materials available were identified, and the written instructions to the VARWARS problem were distributed. Verbal instructions emphasized the three hour time limit, the requirement to solve the problem using only the equipment and materials provided, and the fact that the group's score on the exercise depended solely on the solution provided on their data forms, i.e., no written nor oral justification nor briefing of their solution would be required. During the exercise, three researchers observed the group from an adjoining observation room.

### Variables

The only independent variable was state of training: before or after CAS<sup>3</sup> instruction. Dependent variables consisted of an outcome score and process ratings. The outcome score, or product score, is a single objective measure of the quality of a group's solution (Lussier, 1988). The process ratings represent a consensus rating provided by the three authors using rating scales reflecting the processes used in arriving at the solution. Five process scales, each allowing a maximum of 20 points, were used. The first, Getting Organized, rated groups on their organization into teams, on their time management plan, on their problem definition and restatement, and on their preliminary information gathering. The second process scale, Information Sharing and Coordination, contained twenty items of information which were available to one team but were of value to another team in their decision making. Observers noted each instance where they believed one of these twenty information items was shared with the appropriate team. Some of the information items were facts provided in the instructions. Other items were estimates which needed to be produced by one team to aid another. The third process scale, Decision Making, rated groups on how well they developed courses of action, generated criteria for selection of a course of action, analyzed courses of action, prepared estimates, and selected a course of action. The fourth process scale, Professionalism, rated groups on their dedication to task, error checking, on whether they performed an incremental improvement of a complete solution, and on their ability to work within deadlines and manage time. The last scale, Leadership, rated the assigned leader on providing focus and direction, making and stating decisions clearly, conflict resolution, and keeping the group to an appropriate time schedule.

The three observers rated the groups independently during the exercise and afterward were required to reach consensus on each item. Further details of the process evaluation procedure may be found in Garlinger and Lussier, (1988).

The product score, a measure of the quality of the group solution, primarily reflects the efficiency of the solution, i.e., how many points can be achieved given the fixed resources (time and money) of the problem. Because this is the first experiment using the VARWARS problem, normative data regarding scores are not available. The optimal solution is difficult to determine

exactly but appears to be close to but below a score of 800. A score of 700 or above would appear to be a practical maximum in a time limited situation. Scores in the range of 500-600 are good workmanlike solutions. A group with scores in this range has probably made a large number of small errors but it has made reasonable decisions and implemented them without major error. Scores below 450 almost always involve at least one major error.

### Experiment 1 Results

#### Product Scores

Scores for the 22 groups are shown in Figure 1. The mean score for the 11 entrant groups was 465.3 with a standard error of 25.8 points. The mean score for the graduate groups was 356.4 with a standard error of 34.4 points. As is clear from Figure 1, the entrants scored significantly higher (paired  $t = 2.644$ ,  $p < .025$ ) than the graduates. The relatively small amount of overlap between the distributions is remarkable. It is also notable that the 109 point difference between the groups was not in the expected direction.

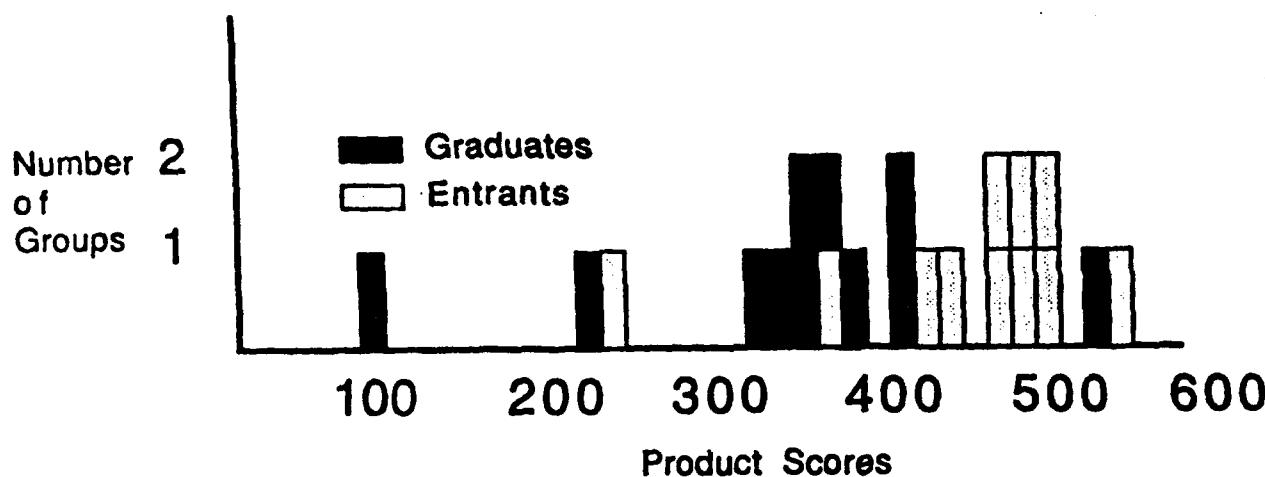


Figure 1. Distribution of VARWARS product scores for graduates and entrants.

#### Process Scores

Table 1 shows the mean process scores for the two types of group. While the entrants exceeded the graduates on all scale items, the difference was significant only for the Information Sharing scale, which measured the transfer of specific information items. The final column shows the reliability coefficients for the three raters, indicating that there was good agreement on the process ratings.

Table 1

## Mean Process Scores for Entrants and Graduates

| Scale                  | Entrants<br>(N=11) | Graduates<br>(N=11) | Difference | Rater<br>Reliability |
|------------------------|--------------------|---------------------|------------|----------------------|
| 1. Getting Organized   | 13.8               | 13.2                | 0.6        | .91                  |
| 2. Information Sharing | 15.8               | 13.3                | 2.5**      | .86                  |
| 3. Decision Making     | 12.5               | 12.4                | 0.2        | .70                  |
| 4. Professionalism     | 12.4               | 10.1                | 2.3        | .95                  |
| 5. Leadership          | <u>13.6</u>        | <u>12.5</u>         | <u>1.1</u> | <u>.95</u>           |
| Total                  | 68.1               | 61.5                | 6.7        |                      |
| Standard Error         | 4.6                | 3.8                 | 6.2        |                      |

\*\* p < .01.

One item meriting closer examination is the "Dedication to Task" item on the Professionalism scale. This item might indicate whether the graduates, after 2 months of class, had experienced a loss of motivation compared to entering students, which could account for the performance decrement. Table 2 shows the number of groups rated in each category on the "Dedication to Task" item.

Table 2

## Distribution of Observer Ratings on "Dedication to Task"

| Category   | Entrants | Graduates |
|--|----------|-----------|
| 1. Excessive amounts of irrelevant behaviors or idleness seriously impaired group performance.   | 2        | 0         |
| 2. Moderate amounts of irrelevant behaviors or idleness had some negative impact on performance. | 1        | 2         |
| 3. Some members failed to maintain attention to task despite prodding.                           | 0        | 1         |
| 4. All team members worked continuously but some required prodding by others.                    | 2        | 7         |
| 5. Entire group showed enthusiasm and attention to task throughout.                              | 6        | 1         |

The difference is not significant, nor did the raters subjectively notice an obvious difference in motivation. Nonetheless, Table 2 does admit the possibility that the groups differed at the highest level, with most of the entrant groups rated as five and most of the graduate groups rated as four.

Another item of importance is "Develop Courses of Action", because it is an essential part of the method taught in the course, i.e., develop several good distinct alternative solutions, establish criteria for comparison, analyze each alternative, and select the best. Table 3 shows the ratings by the observers.

Table 3

## Distribution of Observer Ratings on "Develop Courses of Action"

| Category  | Entrants | Graduates |
|---|----------|-----------|
| 1. Group did not arrive at any overall course of action but worked on completely unintegrated subsolutions.   | 1        | 0         |
| 2. Proposed only one course of action which was accepted with insufficient analysis.  | 1        | 4         |
| 3. Course of action generation proceeded sequentially. A single course of action was analyzed for feasibility before alternatives were considered.  | 8        | 5         |
| 4. Proposed two or more courses of action that were not sufficiently distinct or were inadequate in concept OR group was inefficient and used excessive time in generating courses of action. | 1        | 1         |
| 5. Proposed two or more adequate and distinct courses of action.  | 0        | 1         |

Neither entrants nor graduates followed the method taught, as only one group proposed more than one adequate alternative, and that group failed to complete the process by analyzing both alternatives. The primary process of problem solving employed by both types of groups was to develop a single solution, modifying it as necessary and rejecting it only if it became completely unworkable. The graduates appeared less likely to complete a sufficient analysis, although the difference was not significant.

Relationship between Process and Product Scores

When all 22 groups are combined, there was no significant relationship between product score and overall process score, nor between product score and any of the five scale scores that compose the process score. Table 4 shows correlations between the five process scales and product scores when the entrant and graduate groups are considered separately. Each correlation is based on 11 cases.

Table 4

## Correlations between Process Scales and Product Score

| Process Scale       | Entrants | Graduates |
|---------------------|----------|-----------|
| Getting Organized   | -.44     | -.08      |
| Information Sharing | -.40     | .24       |
| Decision Making     | -.15     | .61*      |
| Professionalism     | -.28     | .47       |
| Leadership          | -.34     | .30       |
| Total Process Score | -.39     | .34       |

\* p < .05.

It is doubtful that the greater product scores found in the entrants when compared to graduates can be attributed to their greater Information Sharing scores because the correlation between Information Sharing and product score for the entrants is negative and nonsignificant. The only correlation reaching significance is between product score and Decision Making scale for the graduate group. The four items which compose this scale and their correlations with product score are shown in Table 5.

Table 5

## Correlations between Decision Making scale items and product scores for 11 Graduate Groups

| Items of Decision Making Scale                  | Correlation with Product Score |
|---|--------------------------------|
| Develop Courses of Action                       | .05                            |
| Generate Criteria for Selection                 | .56*                           |
| Analyze Courses of Action and Prepare Estimates | .69*                           |
| Selection of Course of Action                   | .39                            |

\* p < .05.

Tables 6 and 7 show the categories for the two significant items. For each category the number of graduate groups rated in that category is shown, along with the product scores for these groups.

Table 6

Product scores of graduate groups rated in each category of "Generate Criteria for Selection" item

| <u>Category</u>   | <u>Number of Graduate Groups</u> | <u>VARWARS Product Scores</u> |
|---|----------------------------------|-------------------------------|
| 1. No criteria established. Group seemed unaware of need for criteria.  | 0                                |                               |
| 2. Discussed need for criteria but none established.  | 1                                | 388                           |
| 3. Criteria were proposed but group failed to reach consensus or achieve a common understanding of the criteria.                                | 4                                | 98, 229,<br>337, 361          |
| 4. At least one relevant criteria was proposed but clearly relevant criteria were ignored OR process was inefficient and overly time consuming. | 5                                | 348, 366,<br>398, 423,<br>431 |
| 5. Criteria were relevant, clearly defined and understood, and no clearly relevant criteria were ignored.                                       | 1                                | 541                           |

Table 7

Product scores of graduate groups rated in each category of "Analyze Courses of Action and Prepare Estimates" item

| Category   | Number of Graduate Groups | VARWAks Product Scores |
|--|---------------------------|------------------------|
| 1. No estimate made or estimates based on meager analysis.                                       | 0                         |                        |
| 2. All teams begin work but none complete a satisfactory analysis.                               | 4                         | 98, 229, 337           |
| 3. Only one team analyzed COAs sufficiently.   | 4                         | 348, 366, 388, 398     |
| 4. Two teams analyzed COAs sufficiently.   | 2                         | 423, 541               |
| 5. Each COA was analyzed completely by all teams. Costs and benefits were accurately identified. | 1                         | 431                    |

These two items, in a sense, represent intermediate team products more than process variables. The "Criteria" item involves the determination of what analyses or estimates need to be made while the "Analyze" item measures how many teams complete the analysis satisfactorily. It is therefore not surprising that these variables were correlated with the product score. More surprising possibly is that these items were not significantly correlated (-.16 for "Criteria" and .12 for "Analyze") for the entrants. The entrants and graduates, however, were rather distinct groups. Almost all of the graduate solutions contained major errors, and some made glaring blunders, while most of the entrant solutions could be characterized as having several minor errors and only a few had major errors. Possibly the greater errors of the graduates may have been more evident to the observers. Perhaps the failure to establish appropriate criteria and to perform adequate analyses may be more significant determinants of final score among groups whose final solutions are more error-ridden.

#### Experiment 2 Methods

In Experiment 1, the graduate groups were composed of students in the seventh week of the nine week course because it was felt that students in the eighth and ninth weeks might be showing a motivational "letdown" due to the approaching end of their assignment. In this experiment, 6 groups composed of

students in the 3rd week of CAS<sup>3</sup> training were tested. Students at this point had completed the problem solving block of instruction although they had only participated in about half as many group exercises as the graduate group of Experiment 1. As in Experiment 1, the seven members of each "mid-course" group are drawn from separate classes so that the members had not worked together at CAS<sup>3</sup>. Testing was conducted in the same manner as in Experiment 1.

### Experiment 2 Results

The six midcourse groups had a mean product score of 440.3 points with a standard error of 48.2 points. It is difficult to draw conclusions based on such a relatively small number of groups. The midcourse results are consistent with the previous results in that the average product score fell between the entrants and graduates and was not significantly different from either. The mean process score for the 6 midcourse groups was 61.2 with a standard error of 4.83 which was not significantly different from either the entrants or graduates.

### Experiment 3 Methods

In Experiment 3, 12 groups of CAS<sup>3</sup> students participated in VARWARS exercises. Testing was conducted as in Experiments 1 and 2 with the following four differences. Testing was conducted during Week Six of the course. The groups were not observed by process raters. Groups were tested in their own classroom rather than at the ARI laboratory facility. Finally, six of the groups, the "intact" groups, were each composed of seven students from the same class. Thus, members of the intact groups had been working together on problem solving teams for the previous six weeks. The other six groups, the "mixed" groups, were each composed of seven students from seven different classes as in Experiments 1 and 2.

### Experiment 3 Results

Mixed groups produced solutions with a mean score of 410.5 and standard error of 22.3. Intact groups produced solutions with a mean score of 285.5 and a standard error of 53.5. Despite the small number of groups, the intact group scores were significantly worse ( $t=2.156$ ,  $p<.05$ ) than the mixed groups.

It is not possible to assess the effects of the move from the laboratory to classroom testing; however, the mean score of the mixed groups is consistent with the findings of the previous experiments. Figure 2 shows the mean scores of all five groups in Experiments 1, 2, and 3 plotted as a function of days of CAS<sup>3</sup> training.

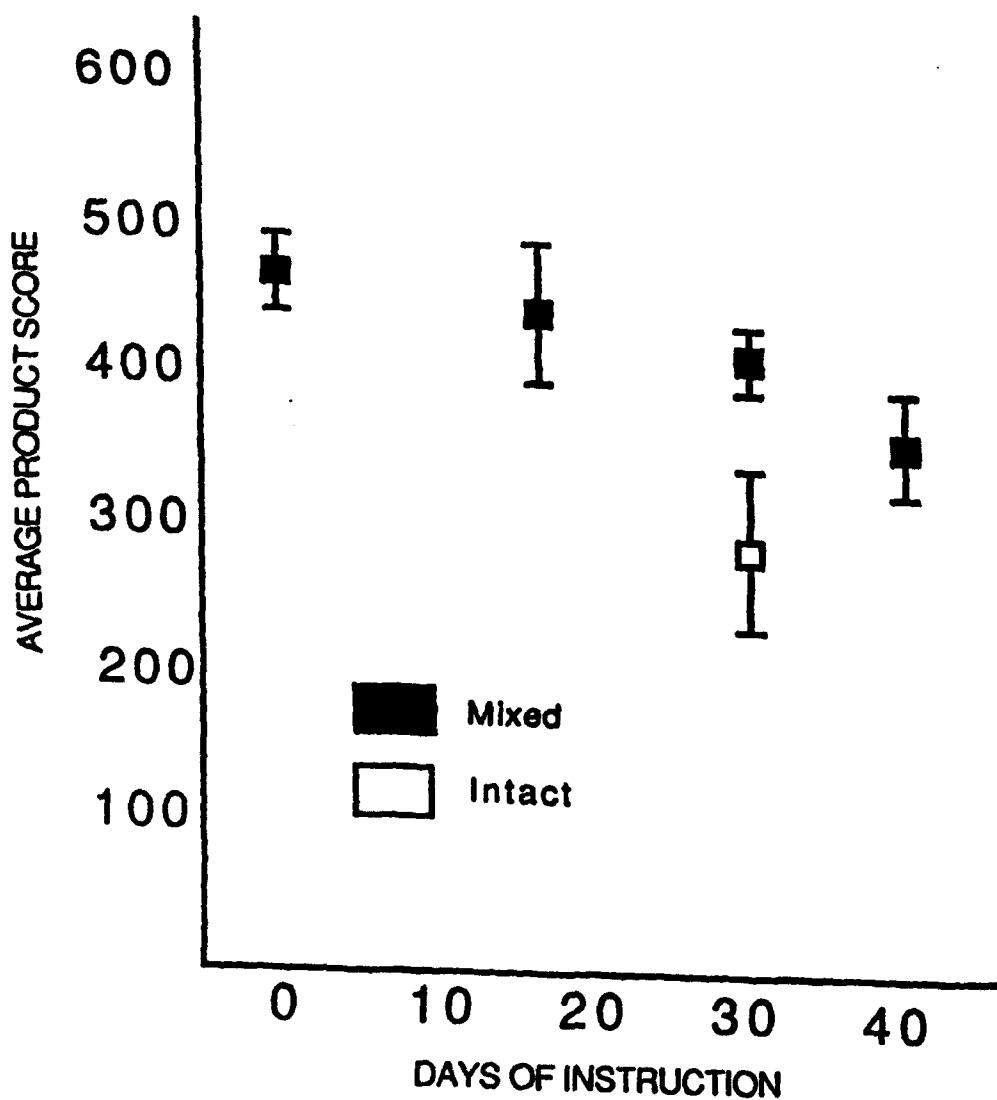


Figure 2. Means and standard errors of the mean for all groups tested in Experiments 1, 2, and 3.

#### Discussion

The major findings were that the graduates performed significantly worse than the entrants and that they did not use the problem solving techniques which they had been taught. The third experimental question, concerning the efficacy of the problem solving techniques could obviously not be addressed because no groups used the techniques.

### Lack of Explanation of Significant Findings

The process variables measured do not help to explain the clear differences in performance between the graduates and entrants because the process variables neither appear to contribute greatly to the product score nor to differ between the entrants and graduates. It is important to realize that most of the solutions by the graduates contained major flaws, while few of the entrant solutions did. Therefore, the important characteristic is not a high level problem solving ability of the entrants. Their solutions were workmanlike at best, taking one of a great many of reasonable solutions and implementing it with only minor errors. The significant effect resulted from the mistake-ridden behavior of the graduates. Moreover, in most of the graduate exercises, one could not blame a single individual. Since the group was divided into two person teams, there was always one person watching and assisting a mistake maker and usually there were several people on other teams who had the opportunity to detect the error. Often the mistakes were made by the group as a whole.

The fairly obvious possibility is that after several weeks in the course, student motivation begins to flag and the students put forth less effort and were more careless, resulting in flawed solutions. This explanation, however, does not indicate why the intact groups scored worse than mixed groups at the same point in the course. Further, a loss of motivation was not apparent to the observers. Considering the observer ratings on the "Enthusiasm and Dedication to Task" item, it seems that if there was a difference in motivation then 1) the difference was small, 2) it affected only one or two members of the group, and 3) it was a difference between good motivation and very good motivation rather than involving low levels of motivation.

It seems probable that patterns of behavior, which are harmful to group problem solving, develop during the course. One possibility is that the group members, who work, play, and live together for nine weeks come to place high value on harmonious relations, and become less critical of one another's efforts. Additionally, punishments in class are almost always directed at an individual - if an individual's work is below standard then he or she must redo it. Students may adopt an "I'll do my job, you do your job" attitude which inhibits satisfactory error-checking among the group.

Another possible explanation for the lower scores of the more advanced groups is that they are mistakenly emphasizing the wrong aspects of the problem. The problems students are trained on tend to begin with a presentation of several good close alternatives. The students are then tasked to choose one and present a cogent defense of their selection. Each of the alternative solutions has merits (or the problem would be easy) so the students may learn that it is not so important which solution is chosen and that the greatest effort needs to go into justifying the decision. In VARWARS, however, the score depends on choosing a good solution.

Several other explanations are also possible. However, whatever may be the cause of the effect, it seems evident that forming mixed groups of students only partially disrupted the tendency of graduates to make major mistakes.

### Relationship between Process and Product

In general, the process items which related to high product scores were those which were closely tied to the problem and to mistakes in intermediate products, i.e., poor or erroneous estimates, neglected criteria, or other major errors. Pure process items addressing, for example, whether the group restated and redefined the problem, whether member qualifications were considered when the problem was subdivided, whether there was a clear time management plan, whether distinct courses of action were proposed, whether the leader made and stated decisions clearly, etc., did not appear to relate to group success in our experiments.

The lack of relationship between some of the process variables and product quality may be due to a lack of variability in our sample rather than to the lack of an actual relationship between the variables. Most groups tested in our sample performed poorly in identifying subproblems and potential solution procedures, in developing alternate courses of action, and in time management. Members rarely used rough estimation correctly to scope the problem and to prune unpromising branches of investigation in a timely manner. Typically, queries for information were either answered immediately in too vague or general a manner or were answered too late in too much detail. Nonetheless, our evidence suggests that quality of the problem solving products in a complex situation are not clearly tied to the problem solving process.

### The VARWARS Problem

One of our goals was to devise an exercise featuring interdependent subgroups and objective scoring. VARWARS worked well because it is complex enough so that, at least with a 3-hour solving period, no single member could absorb all the details and make all the decisions. The problem has to be worked by teams in parallel. Further, the complexity sets an environment of confusion and potential error in which communication between group members becomes a significant determinant of success.

Because of the clear differences between graduates and entrants, and between mixed and intact groups, it seems evident that product scores in VARWARS can discriminate between groups and are not unduly affected by chance factors.

While this study did not directly address the differences between the VARWARS problem and jury-type problems, it seems likely that VARWARS will be a suitable vehicle for conducting such comparisons. The major impact on group score by the mistakes of some members found in this study is consistent with the proposed distinction between VARWARS-type and jury-type problems. Further investigations must address the issue of the efficacy of the prescribed problem solving method, provided that some groups can be induced to use it. Also, the underlying causes of the decline in scores of "trained" problem solvers at CAS<sup>3</sup> must be resolved.

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